THE PRESENT STATE OF PLANNING AND ERECTION OF LARGE EXPERIMENTAL WIND POWER STATIONS

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16. Abstract An investigation into the use of wind-power stations, which are planned for the second 5-Year Plan. The size of stations planned is 5000 kW, and they are to be built in areas of the country where there is a sufficient annual wind speed to justify economic use. The Balaklava experimental station was investigated and results show that it was economical, but new research must be done to improve overall performance.

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THE PRESENT STATE OF PLANNING AND ERECTION OF LARGE EXPERIMENTAL WIND-POWER STATIONS

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The Possibilities of Wind-Power Engineering in the Second 5-Year Plan

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The second 5-Year Plan envisages providing the Soviet Union with tens of thousands of kilowatts in the form of powerful wind-power stations. The history of capitalist technology does not reflect any significant attempts for using wind energy for permanent power stations. In the USSR, socialist economy makes it possible to build wind-power units at suitable points of the territory, which is very important when there is a smaller concentration of wind energy. They can be joined at any point of existing electrical networks. Apart from this, these same conditions make it possible to successfully combine their work with the work of other electrical stations, combined into an overall electrical system, which is a reserve for wind-power stations.

The proposed amount of power created by wind-power stations in the second 5-Year Plan is technically based on the results of preparatory work, done over the past few years by our scientific research institutions in the field of design and experimental construction.[1]

In the massive plans for electrical construction during the second 5-Year Plan, the use of wind can only be effectively used

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[1] The following organizations are engaged in the use of the wind: the Central Wind-Power Institute of the Main Power Industry (TsVEI) in Moscow and the Ukrainian Institute of Industrial Power Engineering in Kharkov.

* Numbers in the margin indicate pagination in the foreign text.

when large stations are set up. Designing indicates that there is a possibility to build in the Soviet Union wind-power stations with a capacity of 5000 kW in each unit. Calculations for the construction and operation of a unit of this type are confirmed by experience of building and operation of a small-capacity experimental station, completed in 1931 in the Crimean autonomous Soviet Socialist Republic, the results of tests of which are shown below.

The Size of the Problem of Constructing Large Wind-Power Stations

The problem of using wind power on a large scale includes a whole number of questions, the solution of which must be solved by building medium-capacity experimental stations. The powerful type of wind motor required for the Soviet Union causes the need to transfer from former multiblade, slow-running windwheels to high-speed motors with a small number of blades, to reduce the weight of the large diameter rotor. The high tip speeds of the blades of high-speed machines require, in their turn, the use of a specially streamlined blade for reducing aerodynamic losses when working in an airflow. In view of the small density of working medium (free flow of air) the geometric dimensions of windwheels and towers acquire great importance, and make the task of economizing in metal more important when the maximum strength of the machine is required. Small wind-power stations which existed earlier operate exclusively on direct current and are equipped with sets of storage batteries for supplying the consumer when there is no wind. In large stations, the bulky sets of storage batteries decrease, so that when operating parallel with other stations, the direct current must be replaced by a three-phase one.

This question, already basically solved at the experimental station in Balaklava, requires further technical development, especially in the use of normal synchronous generators. Apart from this, the installation must be completely automated to reduce

expenditure of personnel, which, on account of the obligatory sparseness of the units, can otherwise be considerable.

Graphs of Wind-Power Station Output

Let us consider some operational features of wind-power stations.

The capacity of a station varies according to the change of wind speed. When it is operated correctly and without the use of accumulator batteries, the load must cover every possible output of units and check the change in them, so that only the excessive, uncovered unit of loading of the network of the stations is always transferred to other stations. In view of this, we shall consider the terms "loading graph" and "possible output graph" of wind-power stations as being equal. When there are synchronous generators, carrying out this condition would have required economic operation for the automatic regulation of generation, asynchronous generators on the first stations can load themselves automatically using the appropriate revolutions until the power limit of the prime engine is reached and do not require adjustment. Units at the station can be established no nearer to each other than 10 times the diameter of their windwheels, otherwise the wind shadow of the vanes of one unit will stop the other one from making full use of the airflow. The speed of the airflow (Fig. 1) is of a rippling nature timewise, and therefore, the power of the unit must also ripple to a great extent. However, when the number of units working in parallel is increased, the total short-term graph of their loading is approximately a straight line. The ratio of the maximum to the minimum equals 4.4 for a rippling graph of loading of one unit; when two units are working in parallel (with

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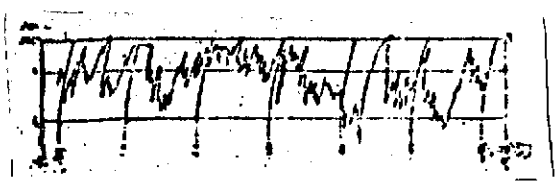

Fig. 1. A diagram of the wind speed over 6 min.

rotors of 30 m in diameter each and at a distance of 200 m from each other, this ratio is 1.92; when three units are working (and the distance is the same), the ratio is 1.8 (Fig. 2).

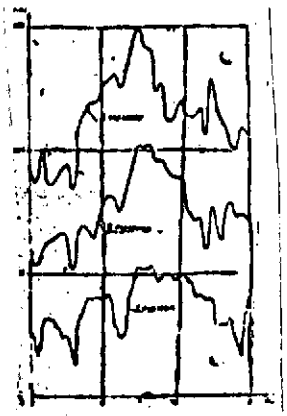

Fig. 2. Output graphs of one, two and three wind units.

[Callouts illegible]

The shape of the daily graph of loading for a given area and time of the year is subject to regularity, but, however, there are frequent deviations. For a great part of the territory of the USSR, the winter daily graph of output of wind-power stations will be more even and higher than the summer one. In Fig. 3. are given the average daily graphs of loading of the Balaklava experimental wind-power station for March and August 1931. The annual aerological conditions are more uniform and there are fewer exceptions (Fig. 4). The annual generation of energy of a station is determined by the aerological conditions of the area and by the operational characteristics of the units, but can also be determined approximately, in theory, if the average annual wind speed of the area is known, by determining the recurrence of wind speeds, suggested by M. Pomortsev. When this method is used, there is some error in determining the graph of power of the station (Fig. 5), and the cumulative error in annual energy degradation can be up to 30%, depending on the calculated wind speed. The number of operational hours of the installed capacity in wind-power stations fluctuated from 2000 to 3500. This figure is dictated by the amount of installed capacity of the unit, selected for a given area and for a given rotor diameter based on economic considerations.

Testing of the No. 1 Unit at the Balaklava Station

The No. 1 unit (Fig. 6) began working in May 1931. It has a high-speed, three-blade motor, with self-regulating and /11

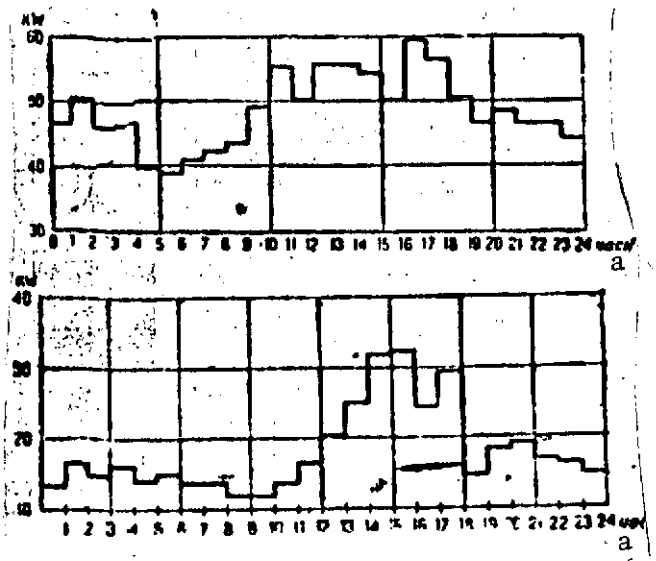

Fig. 3. The daily graphs of loading of No. 1 unit of the Balaklava station. The average calculated generation of electrical energy for March 1931, [illegible] kWh (above), average generation of electrical energy for August 1931 13400 kWh (below).

Key: a. Hours

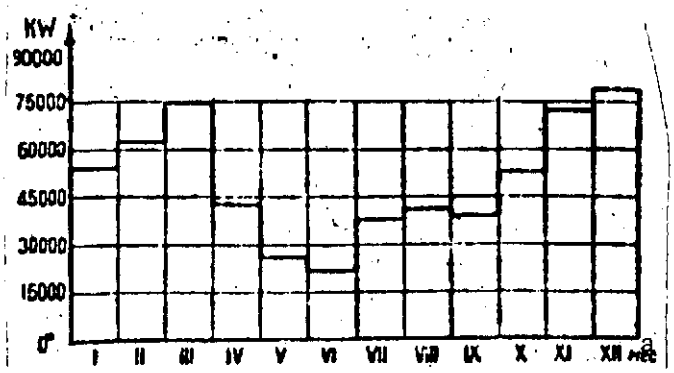

Fig. 4. The annual graph for loading of the Balaklava station 3 × 100 kW for an average wind year (the annual norm of output 600,000 kWh). A result of tests of the No. 1 unit with [illegible] = 30 revolutions/ /min.

Key: a. Months

self-aligning blades, with a capacity of 180 hp. The rotor diameter is 30 m, the number of vane revolutions per min is 30, the asynchronous generator is for 93 kW with a $\cos\phi = 0.84$, and 600 synchronous revolutions per min give a constant overloading of 10%, thanks to the excellent cooling conditions. The station works in parallel with the Sevastopol' steam turbine station and supplies energy to the city network at 6300 V[2]. An asynchronous generator was chosen, since there is a danger when operating with a synchronous generator, owing to some irregularity in the motor rotation when idling and the lack of experimental data, tested in a laboratory. The speed of the motor is measured by the ratio of the tip speed to the wind speed, that is

[2] A precise description of of the station is given in the journal Elektricheskiye stantsii.

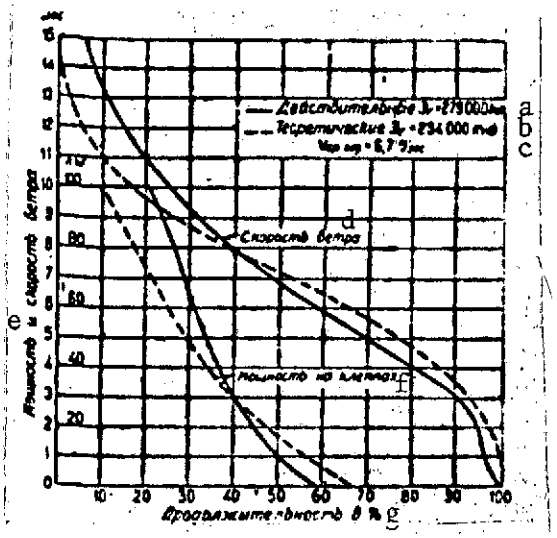

Fig. 5. Duration of wind speed and power for 1931 at the Balaklava wind-power station.

Key: a. Actual energy E[illegible] = 279,000 kWh; b. Theoretical energy E[illegible] = 234,000 kWh; c. [Illegible] = 6.7 [illegible]; d. Wind speed; e. Power and wind speed; f. Terminal power; g. Duration in %

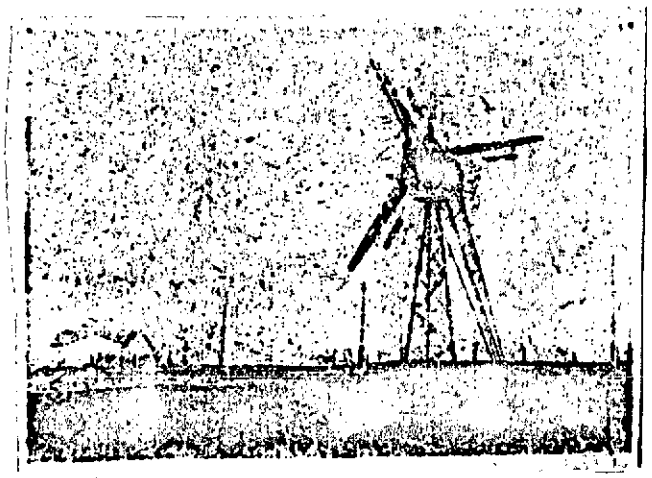

Fig. 6. General view of the No. 1 unit of the Balaklava wind-power station.

$$Z=\frac{\omega R}{v}=4.75.$$

The number of motor revolutions and the adjustment for the most advantageous operational use, when energy is being generated at a maximum, is found by the following method:

Scaling was made of the twisting moment M/Z or of the efficiency factor ξ/Z of curve types in Fig. 9 for power characteristics P/v by substitution into the basic power formula

$$P=C\cdot R^2\cdot v^3\cdot\xi \qquad (1)$$

of values

$$\xi=C_1 MZ \qquad (2)$$

and

$$Z=\frac{\omega\cdot R}{v}, \qquad (3)$$

where R is the radius of the rotor of the wind motor; ξ is the coefficient of wind energy use (aerodynamic efficiency factor of the

blades); v is the wind speed in m/sec; ω is the angular speed of the blade; M is the relative twisting moment of the engine; C, C_1 are the constant coefficients, we find

$$P = C_1 \cdot v^3 \cdot M. \quad (4)$$

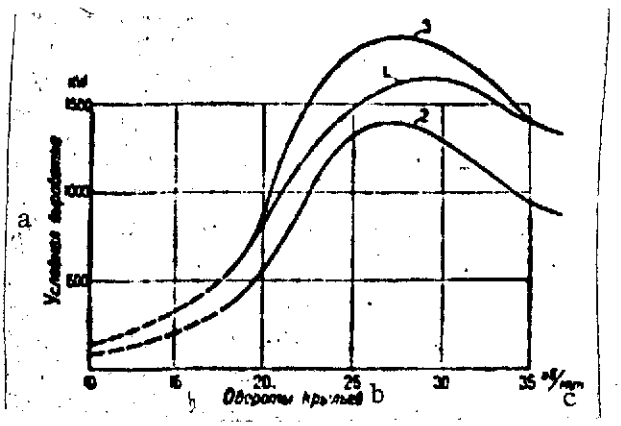

Fig. 7. Calculated generation curves for selecting the number of revolutions: 1 - wind speed V_{av} = 5.2 m/sec recorded on an anemograph for 1930; 2 - wind speed according to Pomortsev V_{av} = 5.2 m/sec; 3 - the same for V_{av} = = 5.75 m/sec.

Key: a. Hypothetical generation; b. Vane revolutions; c. rpm

According to the characteristics M/Z, corresponding to various settings of the blade to the rotor rotation plane at various v, the power on the vanes of the motor is determined for various constant vane revolutions (ω = const). In practice, this means either a selection of another number of generator revolutions, or a change in the gear ratio of the tooth gearing, which transmits power from the windwheel to the generator.

By determining the amount of mechanical loss in transmission and the efficiency factor of the generator, we find the appropriate power on the battery terminals of the generator. Furthermore, we find the amount of annual energy generation, when there are different revolutions and regulation settings for the proposed aerological conditions of the position, in the form of a production sum of wind speed duration for corresponding powers by the characteristics P/v. The results are shown by generation curves (Fig. 7), where preference was given to curve 1, where the aerological

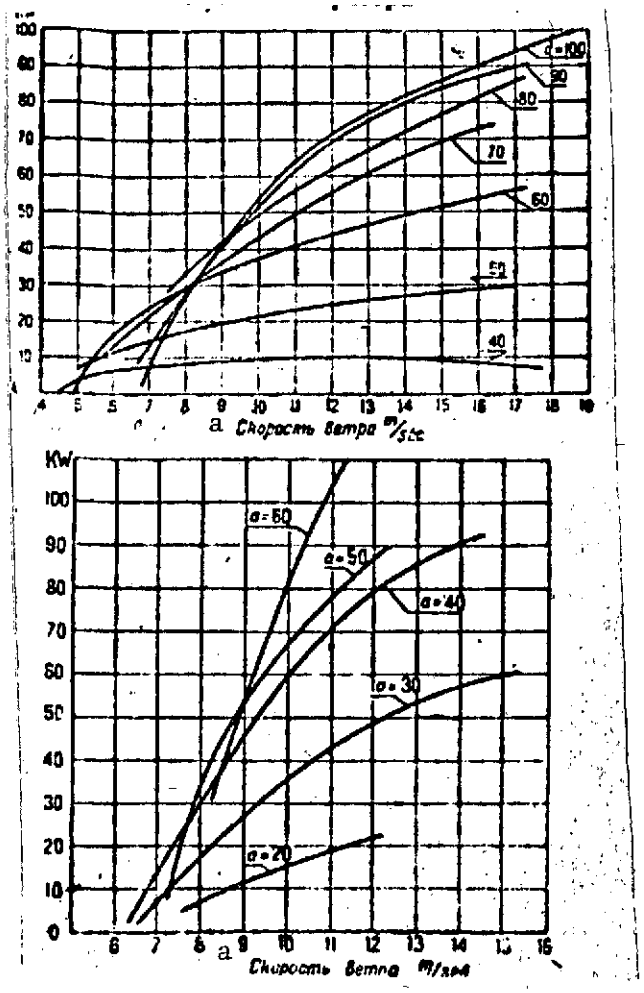

Fig. 8. Experimental characteristics of the unit at the Balaklava wind-power station
Upper when a = 10 rpm
Lower when a = 30 rpm

Key: a. Wind speed in m/sec

conditions were taken of wind speeds recorded on a measuring instrument, set up at the station in 1929. This curve has a maximum when n = 30 rpm. In order to determine the economic advantage of installed capacity for an operational station, one must continue the calculations until ascertaining the cost of energy when the vanes are operated in different conditions and generated powers are set differently.

Testing of the No. 1 /12 experimental unit was done with the motor adjusted at different settings: for 19 and for 30 vane rpm. As was suggested by calculation, the operating conditions for 30 rpm were considerably more economic. The operational conditions obtained are shown in Fig. 8, where results obtained on the power are slightly higher than those calculated. With 30 rpm and a setting arbitrarily shown on Fig. 8, as a = 60, there was a planned capacity of 100 kW with a wind speed of v = 12.1 m/sec. This capacity was obtained during testing with v = 11.0 m/sec. The aerodynamic characteristic of the vanes, rearranged from experimental operational characteristics ξ/Z are shown in Fig. 9. The best

Fig. 9. Aerodynamic characteristics of the vanes of No. 1 unit at the Balaklava wind-power station:
1 - a = 90; n = 19 rpm;
2 - a = 60; n = 30 rpm;
3 - a = 40; n = 30 rpm;

Key: a. Efficiency factor of wind energy; b. Rapidity ...

efficiency factor of the vanes $\xi = 0.242$ was obtained at a speed of $Z = 4.75$.

The small value ξ, which in other motors of this type tested in laboratories exceeds 0.35, can be explained by the narrow blade chosen in order to reduce the weight of the rotor and increase the uniformity of movement, and also by some imperfections in making blades and by the badly crumpled sheathing made from 4 kg of roofing iron, due to the large number of alterations which the blade underwent during the installation period; this was taken into account when calculations were done. Apart from this, it can be hoped that further tests of the unit in later adjustment conditions will give an increased value for ξ.

The following method was chosen for taking the operational characteristics: for measurement, the average 20-min values were taken for the capacity applied to the network on the low side of a 220/6300 V step-up transformer. The average capacity was determined by the difference of readings of a kWh-meter and checked by the reading of a registering wattmeter. The average wind speed, for the same 20-min period, was measured on a mast 25 m high, corresponding to the center of the windwheel of the unit and at a distance of 50 m from it. The wind speed was calculated according to readings on a Fuss registering anemometer with an electrical contact every 500 m along which the wind had passed. Tests were not carried out when the wind was from NE, E, and SE, when the wind shadow of the windwheel could shield

the anemometer. The recording of the power for 7 min is given in Fig. 10.

Operational tests showed that the work of the unit and the automatic equipment, which switched on the generator, switched it off and brought the unit towards the wind when its direction changed, were completely satisfactory.

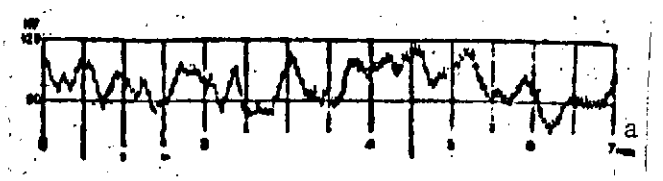

Fig. 10. Recording of the power of No. 1 unit of the Balaklava wind-power station.
Key: a. Min

At the present time, work is being done to enlarge the Balaklava experimental station. During 1933, in order to carry out further operational plans, two modified units of 100 kW are to be set up, which will bring the overall capacity of the station to 300 kW. The aim of enlarging the station is to develop the use of wind-power stations and carry out a number of new experiments. The annual generation of one unit of 100 kW with an average annual wind speed of V_{av} = 5.75 m/sec is expected to be 200,000 kWh in an average wind year.

A Preliminary Design of a 5000 kW Unit

The Wind-Power Institute has completed a preliminary design for a superpowered wind-power unit, at the request of the Main Energy Authority (Fig. 11). The vane of the wind motor has a diameter of 100 m and has three blades. The height of the supporting tower of the unit is 65 m. The blades are self-regulating and the rotating section is of the stabilizer type and stretches for 1/3 of the length. The module of specific speed is Z = 4.75. The number of vane revolutions is n = 12 rpm, selected for economic considerations. Power is transmitted by reduction gear from the windwheel to two generators, each with a capacity

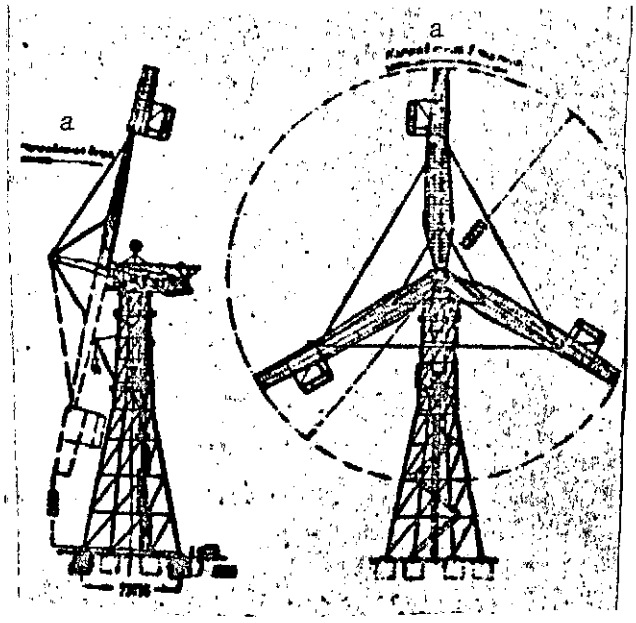

Fig. 11. A design of the 5000 kW unit.

Key: a. Direction of wind; [other callouts illegible]

of 2500 kW, where the second one only switches on when the first overloads. The generators are asynchronous for 6600 V at 600 rpm and cos ϕ = 0.87. One can use synchronous generators, however, only after carrying out laboratory experiments[3]. The overall capacity is 5000 kW designed for a wind speed of v = 16.5 m/sec and an envisaged ξ_{max} = 0.32. For economic considerations, the installed capacity of the unit has been calculated for wind conditions in the Markhotsk Pass (Novorossiysk region), one of the best areas for using wind energy, where the average annual wind speed is V_{av} = 9.5 m/sec; the corresponding average annual speed for a height of 65 m above the ground is suggested as being 11.5 m/sec. /13

In a superpowered unit, attention must be paid to its weight, which, together with the tower, is 600 t. Let us analyze the amount of metal required for building wind-power stations, in comparison with other power plants. The increased amount of metal used and the complexity of machining the parts, if this took place where the wind-power stations were built, would slow down their expanded use.

[3] Although there is an example of satisfactory operation (in America) of hydroelectric plants with a capacity of more than 10,000 kW with asynchronous generators.

Table 1 shows that, according to the weight of metal required, used for creating one kW, wind-power stations can be more profitable than hydroelectric power stations. Owing to the smaller use of installed capacity, on an average 3000 hours, the picture of metal which is used for wind-power stations for 1 kWh of generated energy is less favorable than for large hydroelectric power stations, which have up to 6000 hours use. However, one must bear in mind the recurrent nature of wind energy, as a result of which, in spite of the large expenditure of metal, in comparison with thermal stations, which are burning fuel, wind-power stations are preferable to thermal ones in areas where there are strong winds and insufficient hydroelectric energy. Diesel and locomobile stations cannot compete with wind-power stations in metal consumption.

TABLE 1

Numerical order	Type of power plant	Weight of metal in kg		Expenditure of arbitrary fuel in kg for 1 kWh per year	Number of hours of use of installed capacity
		For 1 kW installed	For 1 kW per year		
1	Steam turbine plants (units 16,000 kW[1])	65	0.015	2700	4500
2	Hydroelectric stations (regional[2])	180	0.030	--	600
3	Wind-power stations (units of 5000 kW)	120	0.040	--	3000
4	Locomobile stations	220	0.070	3500	3000
5	Diesel stations (average capacity)	270	0.90	1100	3000

[1] Without reckoning the weight of metal needed to build approach roads and rolling stock for transporting fuel.

[2] From a collection on the general plan for the electrification of hydroelectric power stations being built in the second 5-Year Plan.

For simplicity of machining, wind-power equipment is far superior to steam and approximately the same as for hydroelectric power.

In the previous article (see Elektrichestvo, No. 14, 1932) regions were shown, in which local wind energy can be used. There was also a number of plans for combined working of wind-power stations with other power plants, since the amount of wind in these areas can be from 20 to 50% of the amount required for electrical energy.